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Sensitivity of Predicted Shallow Water Propagation Loss to Empirical and Extrapolated Bottom Loss Values

Presented at the 123rd Meeting of the Acoustical Society of America, Salt Lake City, Utah, 11-15 May 1992

D. G. Browning
J. M. Monti
J. H. Sammis
P. D. Herstein
F. L. Groneman
Surface Antisubmarine Warfare Directorate

Naval Undersea Warfare Center Detachment
New London, Connecticut

PREFACE

This work was accomplished under NUWC Project No. A62200, the Shallow Water Sonar Initiative (SWSI), P. D. Herstein, Principal Investigator. The SWSI is part of the Surface Ship ASW Advanced Development Program (SASWAD), B. Cole, NUWC Program Manager. This work was sponsored by E. Plummer, PEO USW ASTO B.

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B. F. Cole

B. F. Cole
Head: Environmental and Tactical
Support Systems Department

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D. G. Browning, J. M. Monti, J. H. Sammis, P. D. Herstein, and F. L. Groneman

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13. ABSTRACT (Maximum 200 words)

Historically, the majority of measured bottom loss values were obtained in deep water at grazing angles of 20 deg or greater. An empirical fit to these data, if extended smoothly down to small angles, results in a value greater than 2 dB per bounce at 0 deg. Geophysical models suggest that for hard bottoms, a critical angle would be reached in this low-grazing angle region and that the bottom loss would then drop sharply, reaching a zero value at 0 deg. Under downward refracting conditions in shallow water, low-grazing angle paths may provide, in many cases, the dominant propagation mode. Hence, the value of low-grazing angle bottom loss is critical especially under strongly downward refracting conditions. Following the example of Urick, an empirical bottom loss formula developed by Bell has been modified. At low-grazing angles, its regular value at 10 deg has been linearly extrapolated to intersect a zero value at 0 deg. An analysis is conducted for each formula (empirical and extrapolated) for several shallow-water locations and source-receiver configurations.

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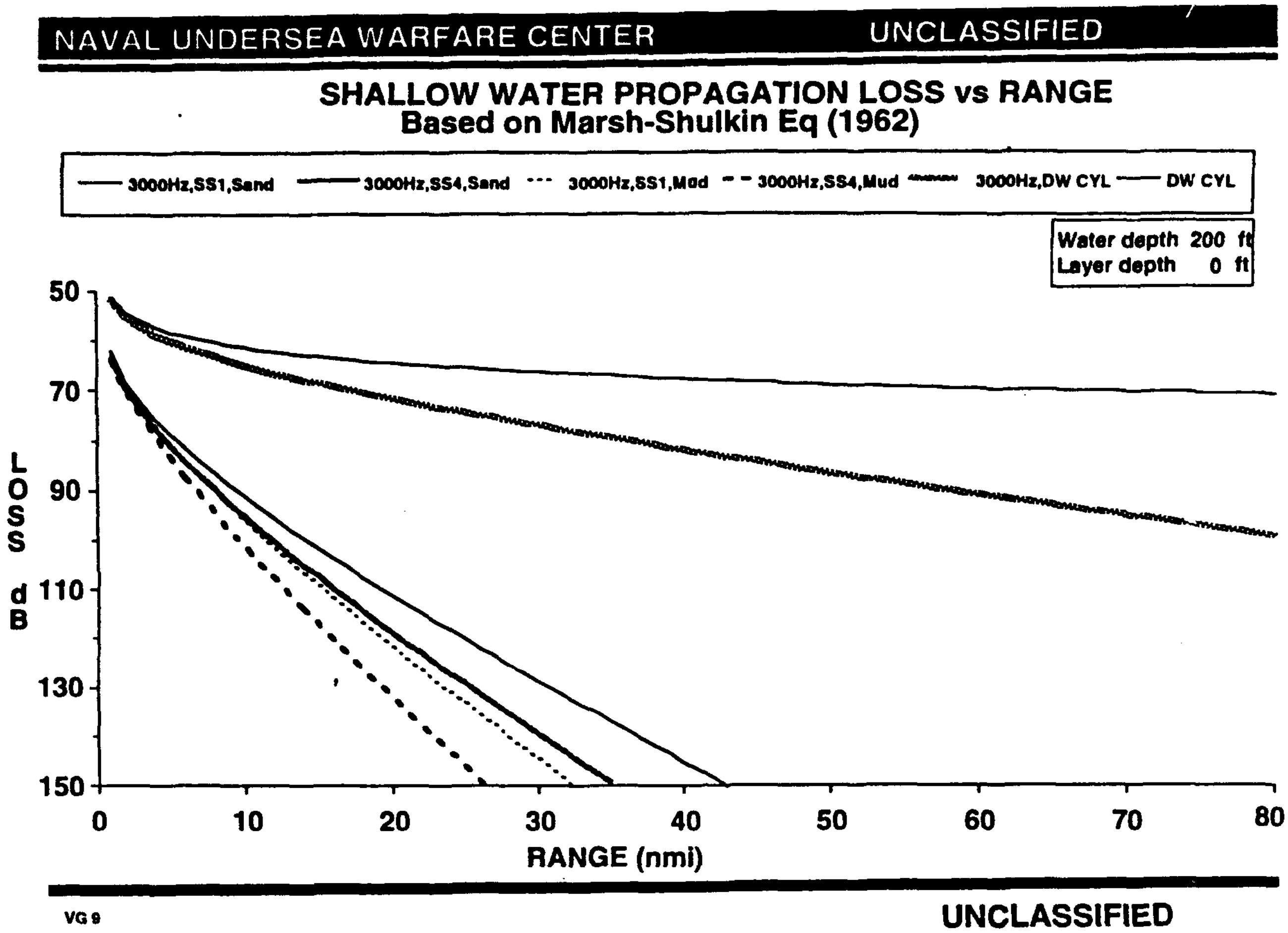
SENSITIVITY OF PREDICTED SHALLOW WATER PROPAGATION LOSS TO EMPIRICAL AND EXTRAPOLATED BOTTOM LOSS VALUES

David G. Browning
Joseph M. Monti
Jeffrey H. Sammis
Peter D. Herstein
Frank L. Groneman

NUWC Detachment New London
New London, CT 06320

VIEWGRAPH 1.

We were faced with the dilemma of what would be the best average bottom loss to use shallow water for propagation loss predictions over a relatively wide frequency range (100 to 5000 Hz). Considering that bottom loss can vary from location to location and also is frequency dependent, we certainly appreciated the difficulties and limitations inherent in such a task.



VIEWGRAPH 2. M-S EXAMPLE

The impact of bottom loss on shallow water propagation under downward refracting conditions is illustrated by this figure. The top curve is propagation loss due to cylindrical spreading only and just below it, cylindrical spreading plus volume attenuation at 3000 Hz.

In comparison, the four lower curves (greater loss) are predictions of the Marsh-Schulkin Colossus shallow water model (reference 1) which includes bottom loss (sand or mud) and surface loss (sea state 1 or 4). The dominance of boundary losses - at 3000 hertz both bottom and surface loss - is evident.

In this paper we will specifically address the sensitivity of shallow water propagation to bottom loss values.

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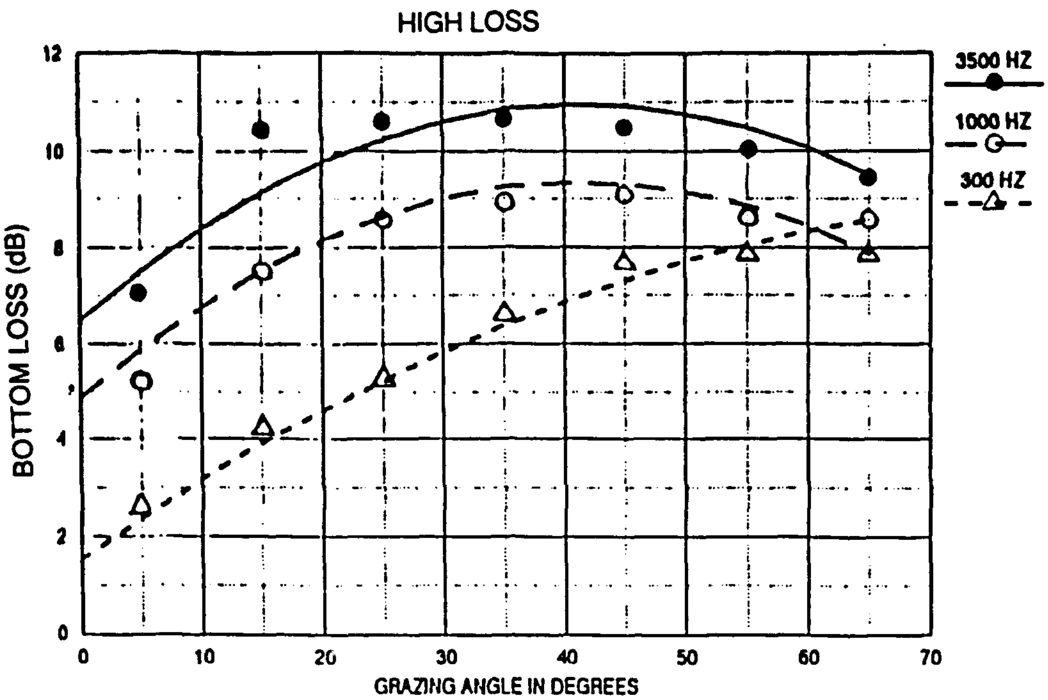

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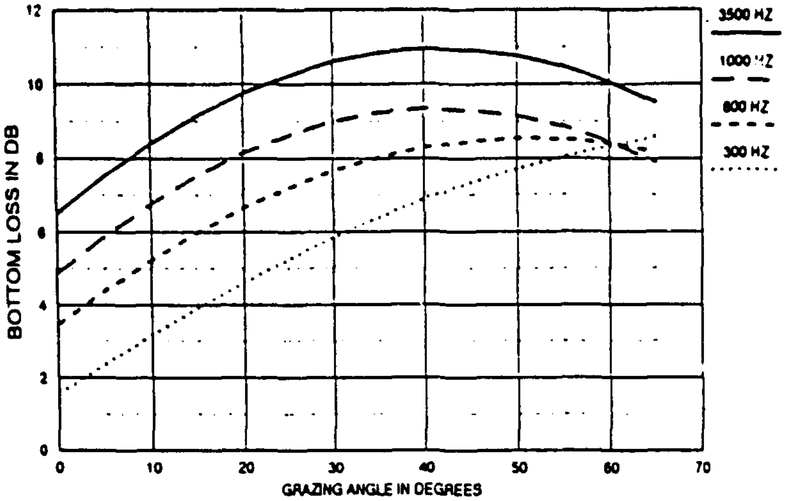
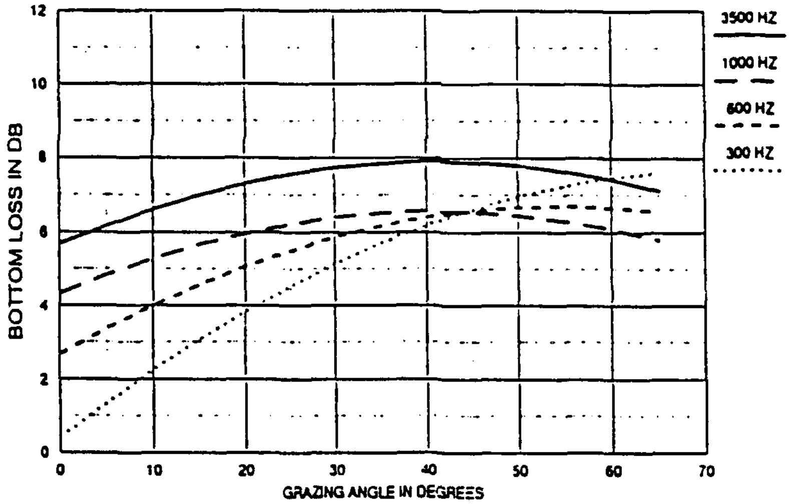
VIEWGRAPH 3. ACOUSTIC BOTTOM LOSS EVALUATION (ABLE) 1

Thad Bell (formally of NUWC) reanalyzed the largest existing total energy bottom loss data base and obtained bottom loss versus grazing angle curves for a wide range of frequencies (50 to 3500 Hz) (reference 2). For selected frequencies, he developed polynomial fits to the data. Shown here are his derived curves (lines) for 300, 1,000 and 3,500 for comparison with smoothed measured bottom loss (points). A principal limitation, however, is that the data base, which was obtained primarily from measurements in deep water, has very little data at grazing angles less than 10 degrees, so that the slope at low angles is just an extension of the polynomial fit determined at higher angles.

HIGH LOSS



LOW LOSS



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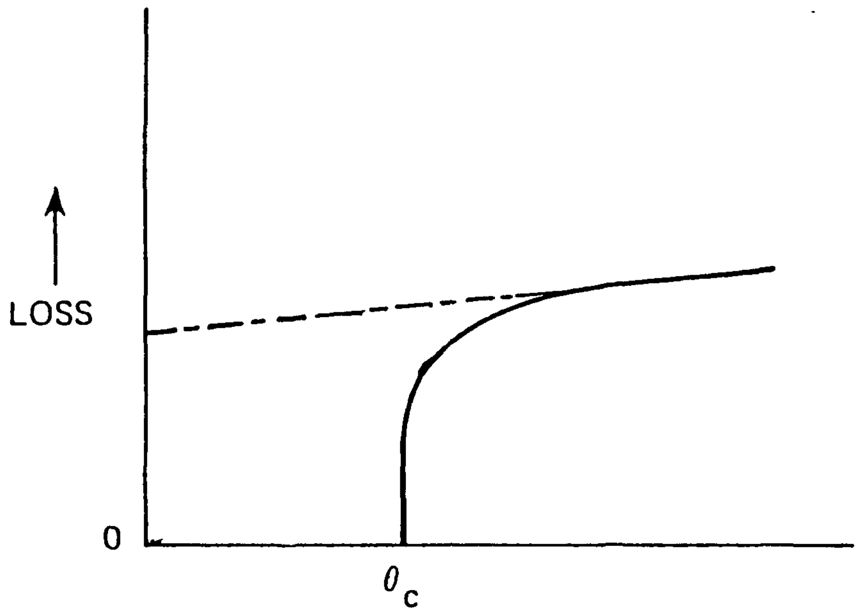
VIEWGRAPH 4. ABLE 2

Bell found that, in order to fit the data set, he must characterize the bottom loss into two types - High Loss and Low Loss. The resulting curves are known as the wideband ABLE curves. For us, these curves had the advantage of representing the average frequency range in which we were interested.



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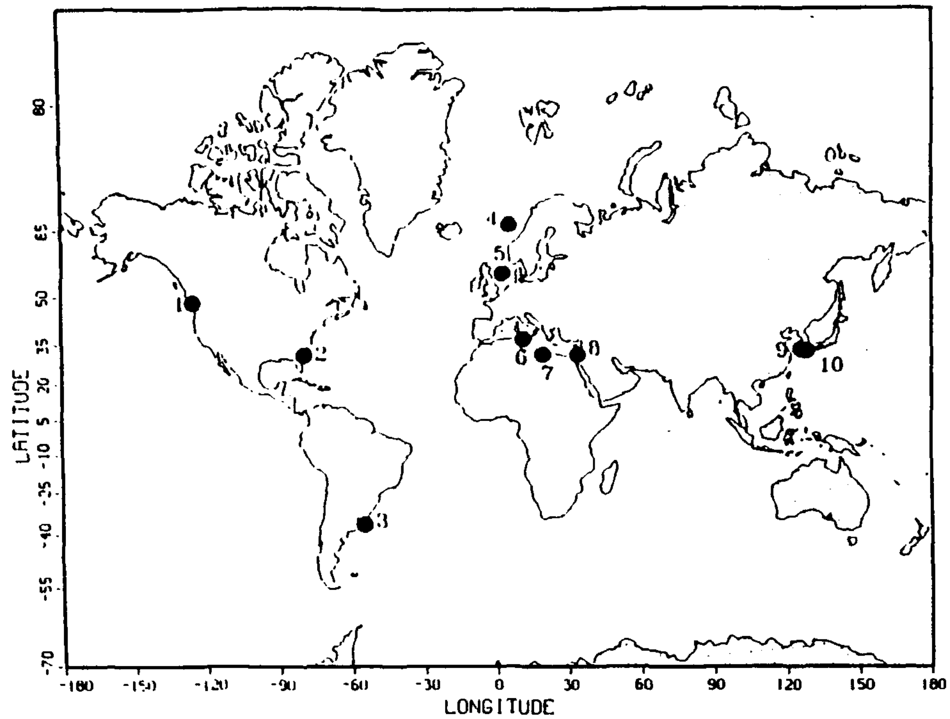
VIEWGRAPH 5. ABLE COMPARED TO NONSPECIFIC CRITICAL ANGLE EXAMPLE

Unfortunately, measurement of low angle bottom loss in both deep and shallow water is quite difficult, and so the existing low angle data are very limited, as was previously mentioned. Therefore, when you make an empirical fit through the entire data base, you are on thin ice below 10 degrees. In reality, the best you can do is continue the trend established at the higher angles, and this results in a positive value at 0 degrees and does not take into account any critical angle effect, illustrated by the dashed line which would be encountered with a "Fast" or "Hard" bottom, that is, a bottom for which both the sound speed and density is greater than that at the immediate overlying water.

At 0 degrees as shown by the dashed line, however, for a "Fast" bottom, that is, a bottom where both the sound speed and density are greater (hence also called a "Hard" bottom) than in the overlying water, the bottom loss is characterized by a critical angle (shown by the solid line) where the loss rapidly increases. Also, in general, the loss is low at angles less than the critical angle. This type of bottom loss reduction can be obtained from geophysical models. One can see that there is a significant difference between the geophysical and extrapolated predictions at low angles.

SHALLOW WATER LOCATIONS



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VIEWGRAPH 6. MAP

We took 10 shallow water sites for analysis with various source and receiver depth configurations. The results were reported at the last meeting of the society (reference 3). We were somewhat apprehensive after finding that the majority of these sites had hard bottoms, so we decided to do a propagation loss comparison with a geophysical (critical angle) bottom loss model.

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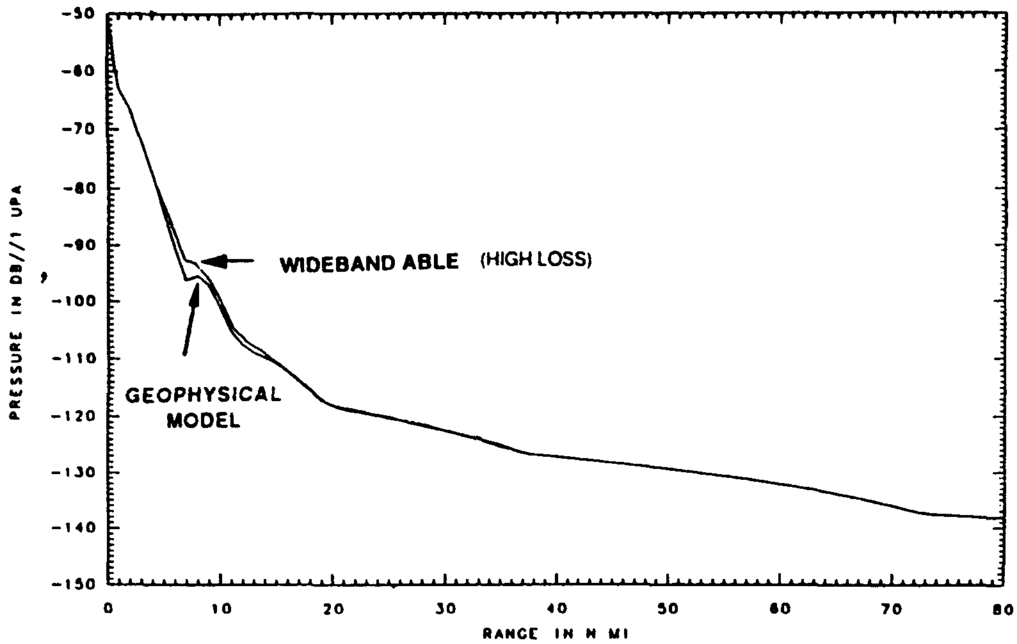
PROPAGATION LOSS
KOREA STRAIT - SUMMER SS = 1
500 HZ SOURCE = 350 FT RECEIVER DEPTH = 500 FT



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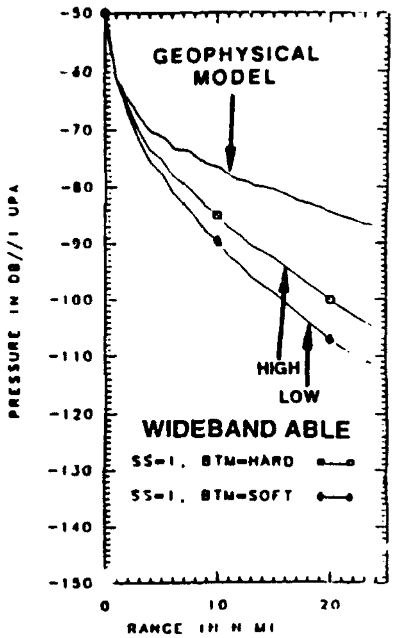
VIEWGRAPH 7. PROPAGATION LOSS COMPARISON - GOOD AGREEMENT

We chose downward refracting (summer) conditions, because they obviously would be the most sensitive to bottom loss. We found that for most sites and source/receiver configurations, there was reasonable agreement between the predictions using the wideband ABLE bottom loss curves and those using a geophysical bottom loss model, as typically shown here.

PROPAGATION LOSS
GULF OF SIDRA - SUMMER
500 HZ SOURCE = 350 FT RECEIVER DEPTH = 275 FT



VIEWGRAPH 8. GULF OF SIDRA PROPAGATION LOSS COMPARISON - BAD AGREEMENT

However, there were several cases where our predictions were extremely pessimistic. These involved strong do\vnward refracting conditions with source and receiver near the bottom.

GRAZING (ARRIVAL) ANGLES OF DOMINANT EIGENRAYS

SUMMER PROFILES - DOWN REFRACTING
RECEIVER ON BOTTOM
RANGE = 20 NMI

LOCATION	SOURCE = 25 FT	SOURCE = "DEEP"
GULF OF SIDRA	10 - 11°	1 - 2°
KOREA STRAIT	11°	4 - 10°
STRAIT OF SICILY	9 - 11°	0 - 4°
JUAN DE,FUCA	9°	0 - 3°
MONTEVIDEO (FEBRUARY)	13°	1 - 2°
NORWEGIAN SEA	11 - 12°	9 - 12°
EAST YELLOW SEA	11°	0 - 1°
KINGS BAY	15°	7 - 8°
NORTH SEA	11 - 12°	0 - 1°
SINAI	11 - 12°	2 - 3°

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VIEWGRAPH 9. EIGENRAY ANGLES

An analysis of the dominant eigenrays for all of the propagation loss predictions gives excellent insight into which propagation loss comparisons would be good and which would not. When the dominant angles were approximately 10 degrees or above. which includes most of the "25 ft source depth" and several "deep" cases (i.e., near the bottom, so the actual depth varies with location), agreement was expected and was good. The problem came with some of the low angle cases which were associated with near-bottom (deep) source/receiver configurations.

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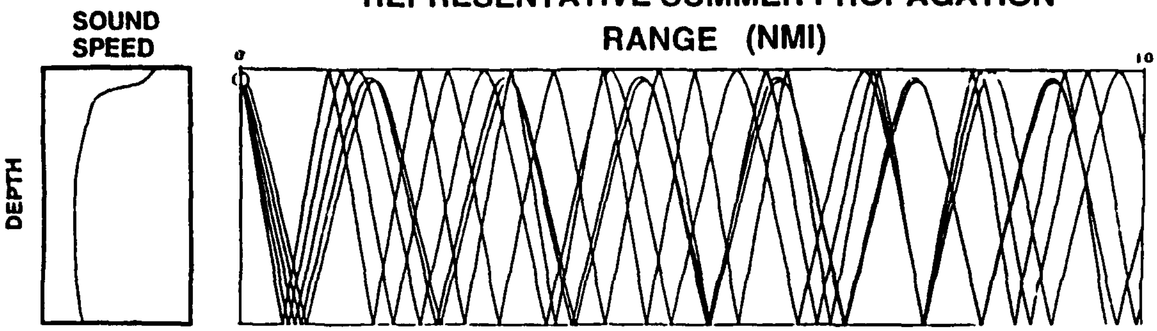
SHALLOW WATER

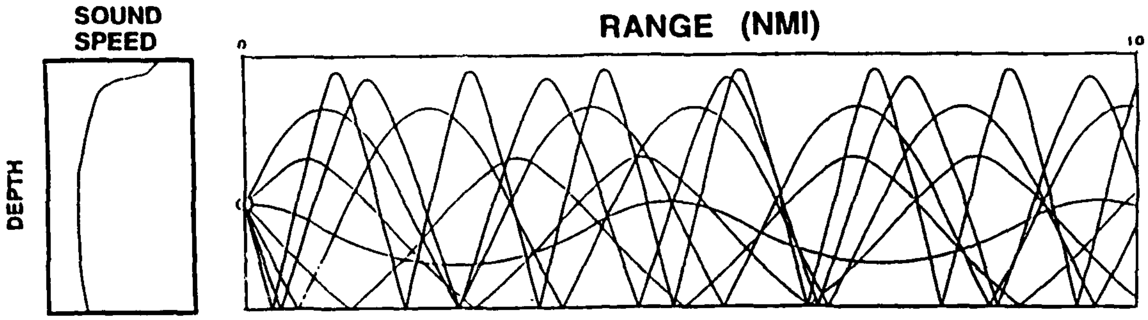
REPRESENTATIVE SUMMER PROPAGATION

RANGE (NMI)



REPRESENTATIVE SUMMER PROPAGATION

RANGE (NMI)



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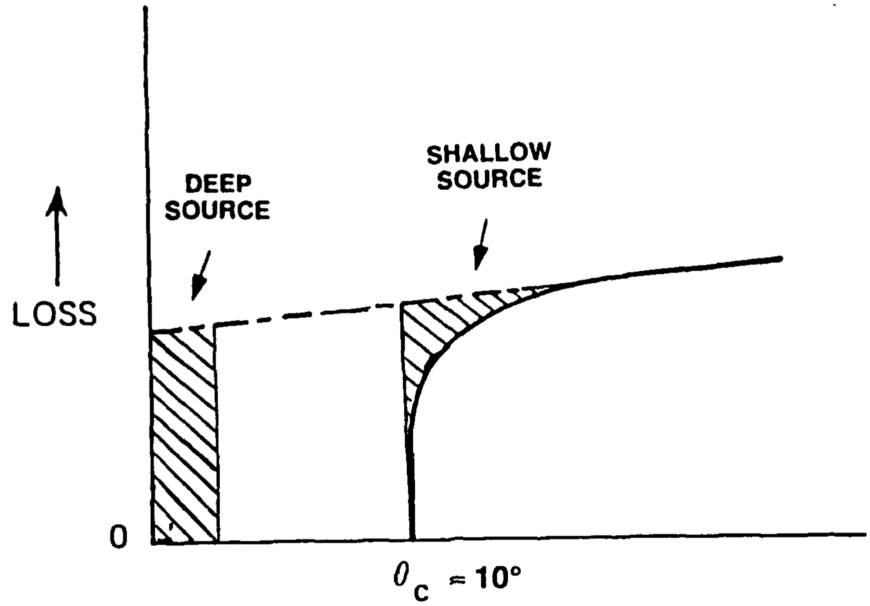
VIEWGRAPH 10. RAY PATH COMPARISON

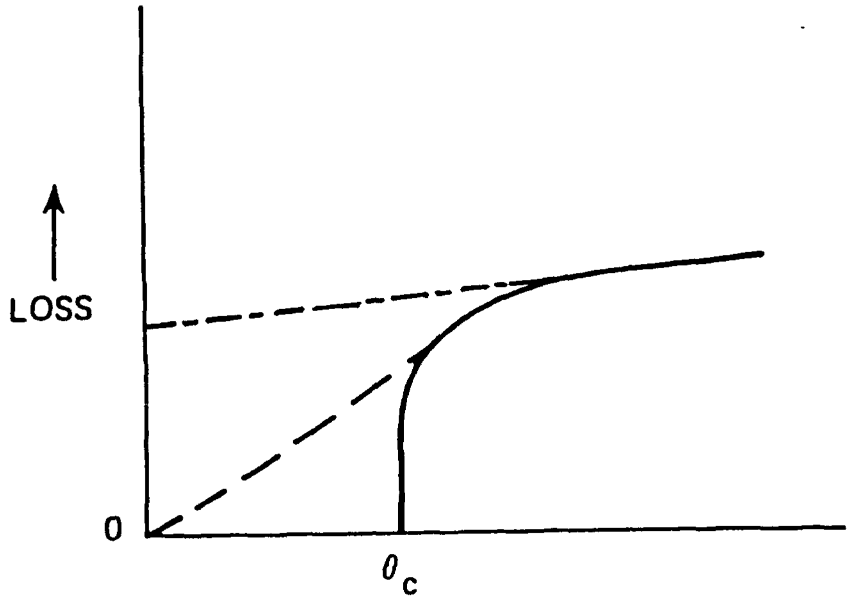
We can illustrate why this would be a problem by using comparative ray diagrams for a shallow water downward refracting case. For a shallow source, all paths result in relatively high grazing angles. However, for a deep source, both high and low angle grazing angle paths are possible. For a hard bottom with a well-defined critical angle, the low angle bottom loss will be significantly lower than the high angle values. As a result, for a deep source, the low grazing angle paths will dominate even though the distance traveled may be longer.

RANGE OF EIGENRAY ANGLES



VIEWGRAPH 11. ABLE-GEOPHYSICAL MODELS EIGENRAY COMPARISON

If we compare an ABLE-type bottom loss curve with a theoretical geophysical bottom loss curve and mark the ranges of eigenray values shown in the previous figure, we can get a good idea of where we would get significant discrepancies in bottom loss and, hence, significant differences in propagation loss predictions. In particular, note the "deep source" cross-hatched area; here we have very low angle eigenrays and, as a result, significant differences in bottom loss between the ABLE and geophysical curves. On the other hand, there are not as significant differences between the curves in the range of eigenrays resulting from a shallow source.

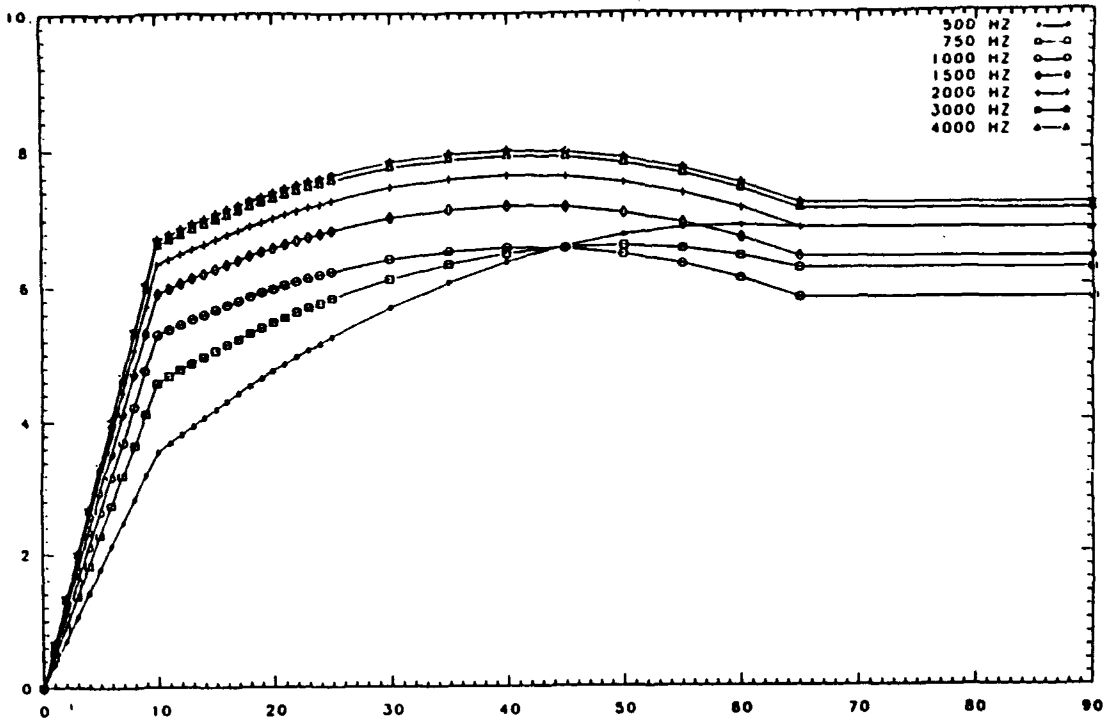


R. J. Urick Sound Propagation in the Sea DARPA, 1979 p. 10-5

VIEWGRAPH 12. URICK FIGURE

Urick has considered a similar problem in his "Propagation of Sound" book (reference 4). He suggests that bottom attenuation would change the bottom loss curve from a step-like critical angle shape to a linear upward slope for the case of a "hard" or "fast" bottom.

BOTTOM LOSS VS GRAZING ANGLE
MODIFIED WIDEBAND ABLE LOW LOSS [HARD] BOTTOM LOSS MODEL



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VIEWGRAPH 13. MODIFIED ABLE

Following this approach, we modified the ABLE fit by linearly extrapolating the value at 10 degrees down to zero. The results for various frequencies are shown here.

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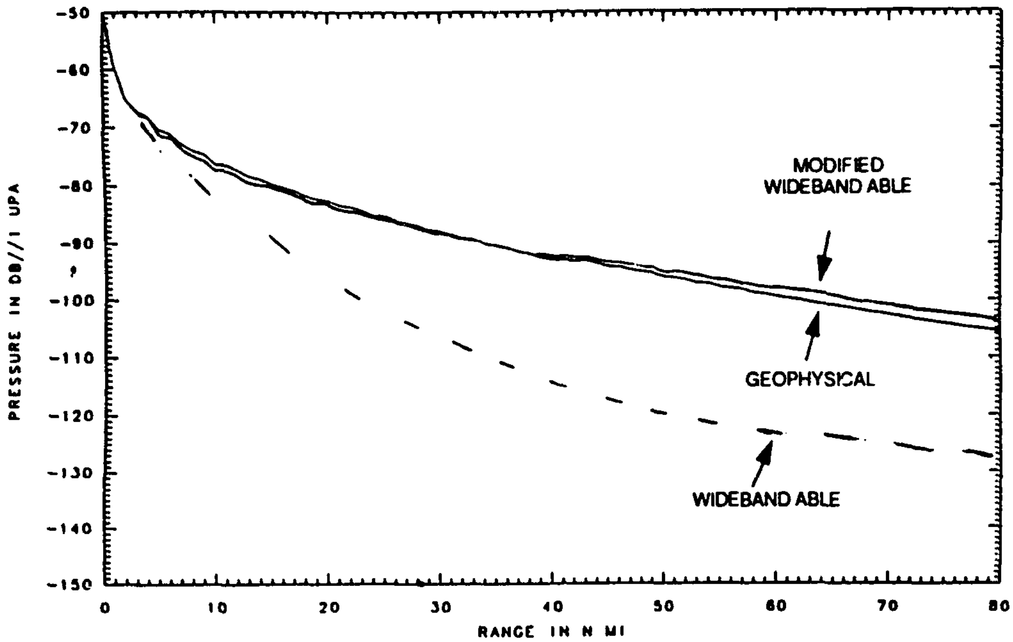
PROPAGATION LOSS
GULF OF SIDRA - SUMMER SS = 1
500 HZ SOURCE = 350 FT RECEIVER DEPTH = 500 FT



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VIEWGRAPH 14. NEW GULF OF SIDRA PROPAGATION LOSS COMPARISON - GOOD AGREEMENT USING MODIFIED ABLE BOTTOM LOSS

If we now revisit our worst case, you can see that the propagation loss, using the modified ABLE bottom loss, agrees well with the predictions using a geophysical bottom loss. The results, using the unmodified ABLE curves, are shown by the dashed line.

SENSITIVITY OF SHALLOW WATER PROPAGATION LOSS CONCLUSIONS

- IN A SHALLOW WATER, DOWNWARD REFRACTING, HARD BOTTOM ENVIRONMENT, ACOUSTIC PROPAGATION BETWEEN A DEEP SOURCE AND A DEEP RECEIVER CAN BE DOMINATED BY LOW ANGLE EIGENRAYS.
- THIS IS DUE TO THE RELATIVELY LOW BOTTOM LOSS AT ANGLES LESS THAN THE CRITICAL ANGLE EVEN THOUGH THE ACOUSTIC PATHS MAY HAVE MORE BOTTOM INTERACTIONS THAN THOSE FOR HIGHER ANGLE REFLECTIONS.
- UNDER THESE CONDITIONS, BOTTOM LOSS CURVES -- BASED ON THE DEEP WATER DATA BASE WITH VERY LIMITED LOW ANGLE DATA SUCH THAT THE SHAPE OF THE CURVE IS BASED PRINCIPALLY ON THE TREND AT HIGHER ANGLES -- WILL OVERESTIMATE BOTTOM LOSS AND THE CORRESPONDING PROPAGATION LOSS.
- WE HAVE FOUND THAT A LINEAR EXTRAPOLATION OF SUCH CURVES FROM THEIR NOMINAL VALUE AT 20 DEGREES (AND ABOVE) TO ZERO AT 0 DEGREES WILL RESULT IN REALISTIC PREDICTIONS OF PROPAGATION LOSS FOR ALL CONFIGURATIONS WE HAVE TRIED UNDER THESE CONDITIONS.

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VIEWGRAPH 15. CONCLUSIONS

In summary, we can say that even under strong downward refracting conditions in shallow water, it is possible to have dominant low angle eigenrays, provided the source and receiver are located near the bottom.

For a hard bottom, that is, a bottom for which the sound speed and density are significantly greater than that of the overlying water, if these angles are less than the critical angle, bottom loss will be relatively low, and an appropriate bottom loss model must be used for accurate predictions.

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3. Joseph M. Monti, Jeffrey H. Sammis, David G. Browning, and Peter D.Herstein, "A Study of Low Frequency Sound in Shallow Water Ducts," J. Acoust. Soc. Am., Vol.. 90, No. 4, Part 2, October 1991, p.2300. (Also see NUWC-NL Technical Document 4011 of 14 February 1992.)

4. Robert J. Urick, "Sound Propagation in the Sea," DARPA, Washington, DC, 1979.

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